SCS
NATIONAL
ENGINEERING
HANDBOOK

SECTION 8

ENGINEERING GEOLOGY

Sept. 1963

SOIL CONSERVATION SERVICE
UNITED STATES DEPARTMENT OF AGRICULTURE

The Soil Conservation Service National Engineering Handbook is intended primarily for Soil Conservation Service (SCS) personnel. Engineers and geologists working in related fields will find much of the information presented here useful to them also.

The handbook is being published in sections, each section dealing with one of the many phases of engineering included in the soil and water conservation program. For easy handling, some of the sections are being published by chapters. Publishing of either sections or chapters will not necessarily be in numerical order.

As sections or chapters are published, they will be offered for sale by the Superintendent of Documents, Government Printing Office, Washington 25, D.C., at the price shown in the publication.

This part of Section 8, Engineering Geology, gives criteria and procedures for making geologic investigations of dam sites and for taking samples for analysis in the Soil Mechanics Laboratory. Their application provides the basic geologic data needed to meet SCS requirements for design and construction.

Washington, D. C. September 1963

For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20250 - Price 40 cents

SCS NATIONAL ENGINEERING HANDBOOK

SECTION 8 -- ENGINEERING GEOLOGY

CHAPTER 3. SAMPLES

CONTENTS

FIGURES

CHAPTER 3. SAMPLES

Samples are obtained for soil mechanics testing to determine the physical properties of materials and how they behave under specific conditions. The results of these tests provide a basis for predicting the behavior of the materials during construction and operation of a structure. Such data furnish a basis for developing certain aspects of the design to provide a safe, economical, and practical structure.

To serve the intended purpose adequately, samples must be representative of the horizon sampled. They must be of suitable size and character so that the desired tests can be performed. The kind of samples to be taken at a particular site depends on the nature of the materials and on the size and purpose of the structure. The number of samples needed depends on the variability of the materials. The minimum requirements for sampling are outlined by group classification in chapter 5.

Determining Sampling Needs

After completing phase 1 of a detailed site investigation (chapter 6), the geologist and engineer must determine what materials should be sampled and what tests are needed. The character of the material and the tests to be performed govern the size and kind of sample required. The selection of equipment and the method of obtaining samples are controlled by site conditions, character of the material, depth of sampling, and the size and kind of samples needed. The kinds of samples to be taken for different locations and tests are outlined in the following pages.

Foundation

Take undisturbed samples of questionable materials at the intersection of the centerline of the dam with the centerline of the principal spillway. Take undisturbed samples at other points along the centerline of the dam if materials of questionable bearing strength, compressibility, or permeability are encountered that cannot be correlated with strata at the intersection of the centerlines of the dam and principal spillway. Always consider taking additional undisturbed samples if the proposed dam is to be more than 35 feet high.

Take 25-pound disturbed samples from each distinct horizon in a proposed cutoff-trench area for compaction analysis if the material that might be excavated is suitable for use in the embankment. Take 4-pound disturbed samples of all other soil horizons and of the same horizons from different holes if they are needed to verify correlation.

Take cores of compaction-type shales for slaking (wetting-drying) and freezing-thawing tests. Foundations of these materials may require special treatment, such as spraying with asphalt or immediate backfilling of the cutoff trench on exposure. Rebound following unloading may also

be a problem in some types of shale. The geologist and engineer should jointly decide what laboratory tests are needed for both soil and rock samples.

Principal Spillway

In addition to samples from the intersection of the centerlines of the dam and principal spillway, take additional undisturbed samples of any other materials of questionable bearing capacity that are beneath the centerline of the proposed principal spillway.

If rock is to be excavated, take undisturbed cores of rock materials. To protect them from weathering, the samples of some rock cores must be dipped in paraffin and stored indoors.

Emergency Spillway

Take large disturbed samples of any material proposed for use in the embankment. If rock is to be excavated, take cores of the rock material.

Although soft shales may be classified as common excavation, it is desirable to obtain cores for later inspection by prospective contractors. If there is any question about the suitability of the rock materials for use in the dam, send cores or samples to the laboratory for freezing-thawing, wetting-drying, rattler, and other tests that will help to determine their physical characteristics.

Borrow Areas

Take large disturbed samples of each kind of unconsolidated material that can be worked as a separate zone or horizon. For classification, collect small samples of materials that are of such limited extent or so distributed that they cannot be worked separately or placed selectively in the fill. Although these less abundant materials generally are mixed with adjoining materials during borrowing operations, their inclusion in samples from the more abundant materials or more extensive borrow zones may result in erroneous evaluation. Laboratory identification of the index properties of these less abundant materials results in better evaluation of the effect and use of various mixtures.

Materials with the same Unified soil classification and from the same horizon and zone can be composited by taking approximately equal amounts of material from each hole that is to be included in the composite. But like materials from significantly different topographic elevations or from different stratigraphic elevations should not be composited.

Do not take composite samples in areas where high salt content, montmorillonitic clay, or dispersion are suspected. In these areas, collect small individual samples from each hole. Samples with like characteristics are composited in the laboratory or testing section after the index properties have been evaluated. The geologist and engineer should furnish guidance on laboratory compositing, based on field distribution of the materials.

On the soil sample list, form SCS-534, show from what holes and at what depth in each hole the materials in a composite sample were taken. Give estimates of the quantity of borrow material represented by each sample on form SCS-35 or in the geologic report.

It is not necessary to sample surface soil that is to be stripped from the site, stockpiled, and later placed on the completed embankment. Since this surface soil is not to be compacted to a required density, compaction tests are not needed.

For sites at which the borrow material is wet and is expected to remain wet during construction, place several samples in sealed pint jars or plastic bags. These samples are needed to determine the field moisture content.

In borrow areas where the water table is permanently high, the collection of borrow samples of cohesive materials below the water table serves no useful purpose unless the area can be drained.

In the geologic report and on form SCS-356, specify what tests other than compaction are needed.

Show the location of all samples on both the plan and the cross sections of the borrow area on the geologic investigation sheets.

<u>Reservoir Basins</u>

Take large disturbed samples that are representative of the bottoms and sides of farm ponds and storage reservoirs for sites where moderate or excessive leakage is suspected. If local materials are to be used for blanketing or sealing, obtain 25-pound samples of each kind. To determine the permeability of reservoirs or pond basins, collect samples from the surface 12 inches of the present or proposed bottom and sides. Where borrow is to be removed from the pond area, take samples from below the proposed borrow depth for permeability tests.

<u>Relief Well and Foundation Drain Locations</u>

If there are permeable strata that may require drainage, take undisturbed samples, if possible, for permeability determinations. If the geologist and the engineer conclude that relief wells or foundation drains are needed, the aquifer must be fully delineated and representative samples taken. Take undisturbed samples of all strata from the surface of the ground to 2 feet below the bottom of the permeable stratum.

It is impossible to obtain an undisturbed sample of some kinds of permeable material. It may therefore be necessary to determine the permeability or transmissibility (permeability times thickness) of an aquifer or aquifers in the field by field permeability tests. If field permeability tests are made, take representative samples for use in the design of the well and filter.

Where corrosion or incrustation of the relief-well screen is a problem take a sample (1 quart) of the ground water. Send it to the laboratory for such tests as alkalinity, chlorides, iron, total hardness, and pH value.

If investigations of the centerline of the dam indicate that foundation drains may be needed, take 4-pound disturbed samples for mechanical analysis of each horizon in which a drain may be placed. These samples usually are of permeable material, but where it is necessary to pass the drain through impermeable horizons, collect samples of this material also.

Stream Channel and Other Areas
If gravels and sands from channels or other nearby areas seem to be suitable for drains or filters, take samples for mechanical analysis.

For Soil Stabilization
Any samples needed for soil-stabilization measures should be representative of the area where the measures are to be installed. The number of samples to be taken depends on the areal extent of the treatment and on the kind or kinds of material. Tests for soil cement or other chemical soil-stabilization measures require very large (75 pound) samples.

Undisturbed Samples

Undisturbed samples are those taken in such a manner that the structure and moisture content of the original material are preserved to the maximum extent possible. Undisturbed samples are used to determine shear strength, consolidation, and permeability. Rock cores are used to determine strength, permeability, and weathering characteristics. Undisturbed samples are generally collected from foundation materials beneath embankments and appurtenant concrete structures when information on natural strength, consolidation, or permeability is needed.

The important considerations for undisturbed samples are that they be representative and that any disturbance of structure and moisture conditions of the sample be reduced to an absolute minimum. This requires close attention to sampling procedures, tools, packaging methods, and transportation.

Undisturbed samples from a depth of more than 15 feet usually must be obtained with drilling equipment. In the absence of drilling equipment, their collection involves the excavation of test pits from which cubes or cylinders of soil can be taken. Cubes, cylinders, or clods of soil can also be cut from the sides of open pits and cut banks, both natural and artificial. See chapter 2 for sampling equipment and methods.

Minimum Size Requirements
The Soil Mechanics Laboratory requirements for trimmed sample sizes and for trimming allowance vary with the homogeneity of the material, the maximum grain size, and the kind of test required.

To meet these requirements, the minimum diameter of undisturbed samples is 5 inches for triaxial shear and horizontal permeability tests and 3 inches for all other tests. In homogeneous material, however, where reliable test results can be obtained from specimens cut from succeeding vertical depths, the minimum diameter for triaxial shear tests is 3 inches.

These minimum diameters apply to material in which the maximum grain size is no more than 2 mm. In materials containing fragments larger than 2 mm., the minimum diameter for undisturbed samples may need to be larger.

The recommended minimum size for rock core samples is NX (2-1/8 inches), but to complete some holes, a smaller diameter may be necessary.

Field Notes

Take detailed field notes for each undisturbed sample. They should include the following items as appropriate.

1. Hole No. and location.
2. Complete log of hole above and below samples.
3. Method of drilling and size of hole.
4. Type and size of test pit.
5. Casing (type and size) or drilling mud mixture used.
6. Ground-water elevation and date and time measured.
7. Length of drive and length of sample recovered, or percent recovery.
8. Size of sample (diameter).
9. Elevations or depths between which sample was taken.
10. Method of cleaning hole before sampling.
11. Other items, such as difficulties in obtaining sample.

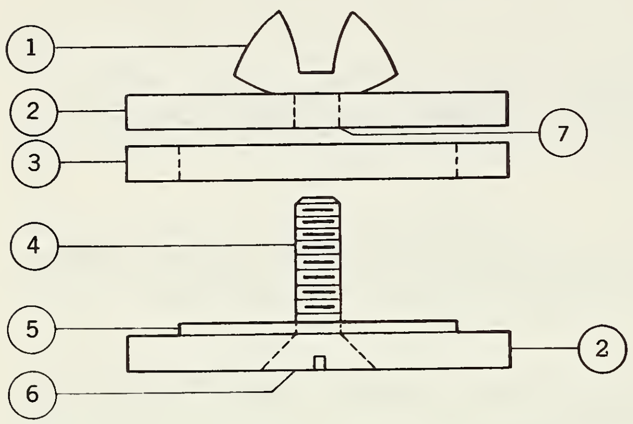
With a permanent marking device, label the sample container. Record the following information on the label.

1. Watershed, site No., and location.
2. Date.
3. Hole No. and sample No.
4. Elevations or depths between which sample was taken.
5. Top clearly identified.
6. Name of person who took the sample.

Packaging

Samples collected in a double-tube core barrel are encased in metal liners when they are removed from the barrel. Plug both ends of these containers with expanding packers or metal caps. Wooden plugs can also be used. If nails are used to fasten the plugs, be careful not to disturb the sample while nailing.

Expanding packers (fig. 3-1) are preferred for sealing the ends of thin-wall tubes, but metal caps, tape, and wax can also be used. Be careful that there is no air space between the sample and the seal. Place labels and all identification on the tube or the liner, not on the ends.



1. Brass wingnut.
2. Aluminum bar stock.
3. Gum rubber gasket.
4. Flathead brass machine screw.
5. Washer.
6. Head sealed with water-proof cement.
7. Drill.

Figure 3-1.--Expanding packer for sample tube.

If they are tightly confined, samples collected by hand excavation can be placed in tin cans, Denison tins, or similar containers.

Seal all undisturbed samples thoroughly with a high-melting-point wax. Beeswax or a mixture of beeswax and paraffin is recommended. These waxes do not shrink away from the container so much as paraffin alone, usually have a higher melting point, and thus deform less in hot weather. The wax seal should fill all spaces between the sample and the container, as well as cover both ends of the sample. Pack all undisturbed samples in excelsior, sawdust, or other shock-absorbent material and crate them. Two or more samples can be boxed together for shipment, but they should not touch each other.

Use reusable boxes. They are to be returned by the laboratory along with sample bags, thin-wall tubes, Denison liners, expanding packers, and the caps for tubes and liners. Mark the boxes with precautionary information, such as "Handle with Care," "This Side Up," "Do Not Drop," and "Protect from Freezing."

<u>Disposition of Rock Cores</u>

Store samples of easily weathered rock cores, such as shale, at the nearest SCS office. If they are left outdoors and allowed to weather, they may give prospective contractors an erroneous impression of their original hardness.

Handle rock cores carefully and store them in boxes of dressed lumber or other suitable materials. The storage boxes should be adequate for cores about 4 feet long. Usually no more than four cores should be stored in each box. The cores should be separated by longitudinal partitions. Use separation blocks wherever core is lost. Embossed metal tape or other

acceptable materials can be securely fastened in the box to indicate by elevation the beginning and end of each reach of core in proper sequence as taken from boring. Place cores first in the top compartment next to the hinged cover and proceed toward the front of the box in the order cores are taken from the drill hole, filling each compartment from left to right in turn (as one reads a book). Note the elevations on separation blocks for those sections in which a core could not be obtained. It is desirable to photograph the cores after they are boxed.

Storage boxes can be fitted with hinged or telescopic covers. On the inside of the cover stencil the box No., project name, site No., and hole No. Stencil the same information on the outside of one end of the box.

Disturbed Samples

To be adequate, disturbed samples must be representative of the stratum, material, or area being sampled. They are used to make qualitative estimates of the probable behavior of materials. This kind of sample is the easiest to obtain and is important for the classification of materials and for many soil mechanics tests. But if quantitative information on in-place strength, consolidation, or permeability is needed, disturbed samples are of little value. The important consideration for disturbed samples is that they be representative of the stratum from which they are taken.

Size

The amount of material needed for laboratory testing depends on two factors: (1) Number, kind, and purpose of tests to be performed and (2) particle-size characteristics of the material to be sampled.

The Soil Mechanics Laboratory has established three general size groups for disturbed samples that are to be sent to the laboratory for testing.

"S" (small) samples are used only for index and classification tests, such as particle-size distribution (mechanical analysis), dispersion, soluble salts, liquid limit, and plastic limit. "S" samples usually consist of 4 to 10 pounds of material collected for purposes of comparison and correlation of stratigraphy and other general soil characteristics of foundations or borrow areas.

"L" (large) samples are used for more comprehensive analyses including index and classification, moisture-density relationships (compaction), permeability, shear, consolidation, and filter-design tests. "L" samples usually consist of 25 to 50 pounds of borrow and spillway material proposed for use in embankments, of reservoir bottom material proposed for sealing, and of aquifer material to be relieved by wells or drains.

"XL" (extra-large) samples are used for special compaction tests, soil-cement tests, and tests for durability as riprap or drain materials.

"XL" samples consist of 75 to 150 pounds of sand or fine-grained materials proposed for soil-cement stabilization or of 40 pounds of rock materials proposed for use as riprap, rock toes or berms, and drainage blankets.

Table 3-1 shows the amount of material that is needed to perform the various soil mechanics tests. These amounts form the basis for the recommended minimum sizes of field samples (table 3-2).

Table 3-1.--Amount of material needed for various soil mechanics tests

Test	Particle size used in test	Amount of material needed
		Pounds
Index and classification tests:		
Sieve analysis (gravel)--------	Passing 3-inch sieve, retained on No. 4 sieve.	3
Hydrometer analysis, dispersion, salts, and Atterberg limits.	Passing No. 10 sieve----	3
Comprehensive tests:		
Compaction--------------------	Passing No. 4 sieve-----	8
Permeability------------------	Passing 3/4-inch sieve--	7
Reservoir sealing-------------	Passing 3/4-inch sieve--	25
Shear:		
For materials in which 90 percent passes No. 4 sieve, specimen size is 1.4 inches by 3 inches.	Passing No. 4 sieve-----	5
For materials in which less than 90 percent passes No. 4 sieve, specimen size is 2.8 inches by 6 inches.	Passing 1/2-inch sieve--	18
Consolidation-----------------	Passing No. 4 sieve-----	2
Specific gravity (coarse fraction).	Passing 3-inch sieve, retained on No. 4 sieve.	2
Special filter-design tests----	Passing 3-inch sieve----	20
Soil-cement tests-------------	Passing 3/4-inch sieve--	70

To fulfill individual test requirements, the size of the sample to be sent to the laboratory varies with the gradation of the natural material. Most laboratory tests are performed on materials passing a No. 4 sieve. Larger samples are therefore needed of materials that contain significant amounts of larger particles. The minimum sizes of field samples for various gradations of materials are shown in table 3-2.

Table 3-2.--Minimum field-sample size for various gradations of material[1]

Gradation of material and sample size group	Maximum particle size	Minimum field sample size
		Pounds
Gradation No. 1, natural materials with 90 percent passing No. 4 sieve:		
"S" sample	3 inches	4
"L" sample	3 inches	25
"XL" sample	3 inches	75
Gradation No. 2, natural materials with 50 to 90 percent passing No. 4 sieve:		
"S" sample	3 inches	10
"L" sample — 1 sample	No. 4 sieve	25
"L" sample — 1 sample	3 inches	25
"XL" sample	6 inches	150
Gradation No. 3, gravel materials with less than 50 percent passing No. 4 sieve:		
"S" sample	3 inches	20
"L" sample	3 inches	40
"XL" sample	6 inches	150

[1] Note that the maximum particle size to be included in field samples ranges from 3 inches for "S" and "L" samples to 6 inches for "XL" samples. Estimate the percentage of over-size materials excluded from the field samples and record it along with descriptions of the samples on forms SCS-533 (Log of Test Holes) and SCS-534 (Soil Sample List). It is not necessary to screen samples to determine the exact amounts of the various particle sizes. Visual estimates of the particle sizes and the quantities involved are adequate.

Put disturbed samples that are to be sent to the laboratory for moisture determination in wide-mouth jars or evacuated plastic bags and seal immediately.

Methods of Obtaining

Representative disturbed samples are obtained by hand excavation or, at a greater depth, by bucket-type augers or drive samplers (table 2-8). Be careful not to contaminate the sample with materials from other strata. Continuous-flight augers and wash borings are unsatisfactory. Take proportionate volumes of all material between the selected elevations in the sample hole. If the sample so obtained is too large, it can be reduced by quartering after it is thoroughly mixed.

Sample Containers
Place disturbed samples in heavy canvas bags. Each State should maintain a supply of these bags.

Table 3-3 relates the size of sample bags to capacity. If it is necessary to retain the field moisture content for laboratory determination, such as in borrow material that is wet and is expected to remain wet, use polyethylene plastic liners inside the canvas sample bags. Suitable liner sizes are given in table 3-3.

Table 3-3.--Capacity of various sample bags

Sample-bag measurements	Plastic liner		Capacity
	Thickness	Size	
Inches	Inches	Inches	Pounds
9 x 15	0.0015	5 x 3-1/2 x 14	10
16 x 24	0.002	10 x 4 x 24	50
16 x 32	0.002	10 x 8 x 30	75

Labeling, Numbering, and Shipping
Tag bag samples of disturbed material with cloth (linen) shipping tags that show the following information: (1) Location of project (State and town or community), (2) site or project name and No., (3) fund classification of project (FP-2, WP-1, WP-2, CO-1), (4) location of sample on the site (centerline station, borrow grid, etc.), (5) test hole No., (6) field No. of sample, (7) depth of sample, and (8) date and name of collector. Number composite samples and show this number on the tag. Record the Nos. of the individual holes from which the composite sample was taken and the field Nos. of the samples on form SCS-534.

Since tags are often pulled off in transit, place a duplicate tag inside the bag.

To expedite the sorting, numbering, and handling of samples in the laboratory, the field No. of a sample should start with the test-hole No., followed by a decimal that indicates the No. of the sample from that hole. Examples are sample Nos. 1.1, 1.2, 1.3, which are three samples from test hole No. 1 (in the centerline of the dam), and sample Nos. 101.1 and 101.2, which are two samples from hole No. 101 (borrow area).

Under separate cover send the standard forms containing the descriptions of the samples and logs of the test holes to the laboratory along with copies of plans and profiles at the same time the samples are shipped.

Send a copy of the geologic report to the laboratory as soon as possible. A summary of the material to be sent to the laboratory follows.

1. Form SCS-533, Log of Test Holes.
2. Form SCS-534, Soil Sample List--Soil and Foundation Investigations. On this sample list show the individual holes, or the samples, included in composited samples if such mixtures are prepared in the field. Record the method of transportation and information concerning Government bills of lading. List the samples on form SCS-534 in this order: Foundation area, principal spillway, drainage and relief wells, channel, emergency spillway, and borrow area.
3. Forms SCS-35A, -35B, and -35C, Plan and Profiles for Geologic Investigations.
4. Copy of the geologic report, including the supplement on interpretations and conclusions.

At the time the samples are sent to the laboratory, send copies of the various forms and of the geologic report including the supplement to the State office. This information is needed to prepare form SCS-356, Request for Soil Mechanics Laboratory Test. Form SCS-356 is an administrative form used to commit funds to reimburse the laboratory for the cost of sample analyses. An alternate procedure is to supply the State office a copy of form SCS-356 that already contains the information that the geologist needs to supply.

Large bag samples are usually shipped by freight or express. Be sure that each bag is correctly labeled and addressed. Small bag samples can be packaged together and shipped by freight or express. Single small bag samples not exceeding 4 pounds in weight can be sent by franked mail. Get a Government bill of lading from the State office if samples are shipped by freight or express.

CHAPTER 4. LOGGING TEST HOLES

CONTENTS

FIGURES

CHAPTER 4. LOGGING TEST HOLES

Logging is the recording of data concerning the materials and conditions in individual test holes. It is imperative that logging be accurate so that the results can be properly evaluated to provide a true concept of subsurface conditions. It is equally imperative that recorded data be concise and complete and presented in descriptive terms that are readily understood and evaluated in the field, laboratory, and design office.

The basic element of logging is a geologic description of the material between specified depths or elevations. This description includes such items as name, texture, structure, color, mineral content, moisture content, relative permeability, age, and origin. To this must be added any information that indicates the engineering properties of the material. Examples are gradation, plasticity, and the Unified soil classification symbol based on field identification. In addition, the results of any field test such as the blow count of the standard penetration test must be recorded along with the specific vertical interval that was tested.

After a hole is logged, it should be plotted graphically to scale and properly located both vertically and horizontally on the applicable cross section or profile on form SCS-35. Correlation and interpretation of these graphic logs indicate the need for any additional test holes and their location and permit the plotting of stratigraphy and structure and the development of complete geologic profiles. Analysis of the geologic profile frequently gives more information on the genesis of deposits.

Field Notes

Data from test holes can be logged directly on the standard form or in a separate notebook. Field notes should contain all the data for both graphic and written logs and also any information that is helpful to a geologist in making interpretations but that is not entered in the log.

Items to be considered in logging a test hole follow.

1. Hole No., location, and surface elevation.--Number holes in the sequence in which they are drilled within each area of investigation. These areas have been assigned standard Nos. (chapter 7). Show location by station No. or by reference to some base. Show elevation above mean sea level if it is known, otherwise elevation from an assumed datum.
2. Depth.--Record the depth to the upper and lower limits of the layer being described.
3. Name.--In unconsolidated materials, record the name of the primary constituent first, then as a modifier, the name of the second most prominent constituent, for example, sand, silty. Usually two constituents are enough. If it is desirable to call attention to a third, use the abbreviation w/________ after the name, for example, sand, silty w/cbls (with cobbles).

4. Texture.--Record size, shape, and arrangement of individual minerals or grains. In consolidated rock, descriptive adjectives are usually enough. In unconsolidated material, use descriptive adjectives for size and give an average maximum size in inches or millimeters. Record shape by such terms as equidimensional, tabular, and prismatic and by the degree of roundness (chapter 1). Record arrangement by estimated relative amounts. Record the gradation for coarse-grained unconsolidated materials and the sorting for poorly graded materials.
5. Structure.--Describe any features of rock structure that you observed, such as bedding, laminations, cleavage, jointing, concretions, or cavities. Where applicable, include information on size, shape, color, composition, and spacing of structural features.
6. Color.--Record color for purposes of identification and correlation. Color may change with water content.
7. Moisture content.--Note whether the material is dry, moist, or wet.
8. Mineral content.--Record identifiable minerals and the approximate percentage of the more abundant minerals. Describe any mineral that is characteristic of a specific horizon and record its approximate percentage even though it occurs in very minor amounts. Record the kind of cement in cemented materials.
9. Permeability.--Estimate the relative permeability and record it as impermeable, slowly permeable, moderately permeable, or rapidly permeable. If a field permeability test is run, describe the test and record the results.
10. Age, name, and origin.--Record geologic age, name, and origin, for example, Jordan member, Trempeleau formation, Cambrian age; Illinoian till; Recent alluvium. Use the term "modern" for sediments resulting from culturally accelerated erosion, as established by Happ, Rittenhouse, and Dobson in 1940. Distinguish between Recent and modern deposits. For valley sediments, identify the genetic type of the deposit and the association to which it belongs. Such identification helps in correlation and in interpreting data from test holes. Similarly, knowing that a material is of lacustrine or eolian origin or that it is a part of a slump or other form of mass movement helps in evaluating a proposed dam site.
11. Strength and condition of rock.--Record rock condition by strength (chapter 1), degree of weathering, and degree of cementation.
12. Consistency and degree of compactness.--Describe consistency of fine materials as very soft, soft, medium, stiff, very stiff, and hard. Describe degree of compactness of coarse-grained soils as very loose, loose, medium, dense, and very dense (tables 2-1 and 7-2).
13. Unified soil classification symbol.--For all unconsolidated materials give the Unified soil classification symbol. In this classification, borderline materials are given hyphenated symbols, such as CL-ML and SW-SM. Ordinarily, this borderline classification cannot be determined in the field. If there is any doubt about the proper classification of material, record it as "CL or ML" and "SW or SM" and not by the borderline symbols. Record the results of field-identification tests, such as dilatance, dry strength, toughness, ribbon, shine, and odor (chapter 1).

14. Blow count.--Where the standard penetration test (chapter 2) is made, record the results and the test elevation or depth. This test shows the number of blows under standard conditions that are required to penetrate 12 inches or, with refusal, the number of inches penetrated by 100 blows. The latter is commonly recorded as 100/d, where d equals the number of inches penetrated in 100 blows.
15. Other field tests.--If other field tests are made, record the results and describe each test well enough so that there is no doubt as to what was done. Examples are vane-shear test, pressure test, field-density test, field tests for moisture content, acetone test, and the use of an indicator such as sodium fluorescein to trace the flow of ground water.
16. Miscellaneous information.--Record any drilling difficulties, core and sample recovery and reasons for losses, type and mixture of drilling mud used to prevent caving or sample loss, loss of drilling fluid, and any other information that may help in interpreting the subsurface condition.
17. Water levels.--Record the static water level and the date on which the level was measured. Wait at least 1 day after the hole has been drilled to measure the water level to allow time for stabilization.

Graphic Logs

For correlation, show individual graphic columns at their correct location and elevation on forms SCS-35A, -35B, and -35C, Plan and Profiles for Geologic Investigation. Use the geologic symbol patterns shown in the legend on form SCS-35A. It is important that graphic logs be plotted to scale and properly referenced to elevation. Use mean sea level (m.s.l.) for the reference plane if possible or an assumed datum if m.s.l. is not known. Graphic columns that are off the centerline profile may show as being above or below the ground level of the profile, depending on the ground elevation of the boring. In this event, make a notation at the top of the column that shows the location in respect to the centerline of the profile.

Indicate the location of the static water table by a tick mark at the correct elevation and record the date of measurement. Show the Unified soil classification system symbol next to each stratum on the graphic column as a further guide to interpretation and sample requirements. To the left of the graphic log, record the blow count opposite the specific horizon tested. Use adjectives and their abbreviations given in the legend on form SCS-35A for other salient features of the material, for example, wet, hard, mas. (massive). On both plans and profiles number the holes according to their location. On plans show the location of holes by the proper symbol and indicate whether the hole was sampled.

Plot the graphic log as soon as a particular hole has been drilled. Where the space provided on SCS-35A, -35B, and -35C is too small to permit plotting at a scale that shows the information legibly, use form SCS-315. An HB pencil is recommended for plotting. Keep the pencil point fairly sharp or use a thin-lead mechanical pencil. Use enough pressure to make the lines and lettering dense and opaque. Keep the work neat and accurate.

Recommended Scales

The horizontal scale used should be such that the graphic logs are spaced far enough apart for the necessary information to be shown legibly. The vertical scale used should be such that the vertical sequence can be depicted adequately. The following scales are recommended for the different features of a site.

A. Vertical--1 inch equals 10 feet. Increase it to 1 inch equals 5 feet for special situations, such as complex logs in which many thin horizons need to be delineated accurately.

B. Horizontal.
   1. Plan of site (all components)--1 inch equals 100 feet.
   2. Profiles.
      a. Centerline of dam, emergency spillway, and borrow grids--1 inch equals 100 feet.
      b. Centerline of principal spillway and the stream channel below the outlet end of the principal spillway--1 inch equals 50 feet.
      c. Centerline of foundation drains, relief-well collector lines, and sediment-pool drain lines--1 inch equals 50 feet.

      If necessary because of the size of the structures, the scales for items 1 and 2a can be reduced to 1 inch equals 200 feet, provided there is adequate space for the graphic logs.
   3. Cross section of stream channel--a scale that requires no more than 2 inches for the plotted bottom width nor more than 6 inches for the entire cross section. Usually, a scale of 1 inch equals 20 feet is practical.
   4. Cross section of emergency spillway--a scale that results in a plotted bottom width of at least 2 inches. Usually, a scale of between 1 inch equals 20 feet and 1 inch equals 100 feet is satisfactory.

Geologic Profile

Develop tentative correlation lines as soon as possible. This helps to determine where additional test holes are needed. As more graphic logs are plotted, the stratigraphic relationships become more definite. Interpretation of data in terms of the genetic classification of the deposits helps to establish correlation. Conversely, development of the geologic profile often helps to interpret the origin of the deposits. When the geologic profile is complete, it provides an interpretation of the factual information from the logs in terms of the stratigraphic and structural relationships along the plotted profile. To this profile add notations on any important condition or characteristic, such as ground-water level, permeability, density, genesis, sorting, degree of weathering or cementation, upstream and downstream continuity, mineralogy, and rock structure. Figure 4-1 shows part of the geologic profile along the centerline of a proposed structure and illustrates some of these points.

Plot profiles or sections drawn normal to the direction of streamflow as though the observer is looking downstream. Plot those drawn parallel to the direction of streamflow so that streamflow is from left to right.

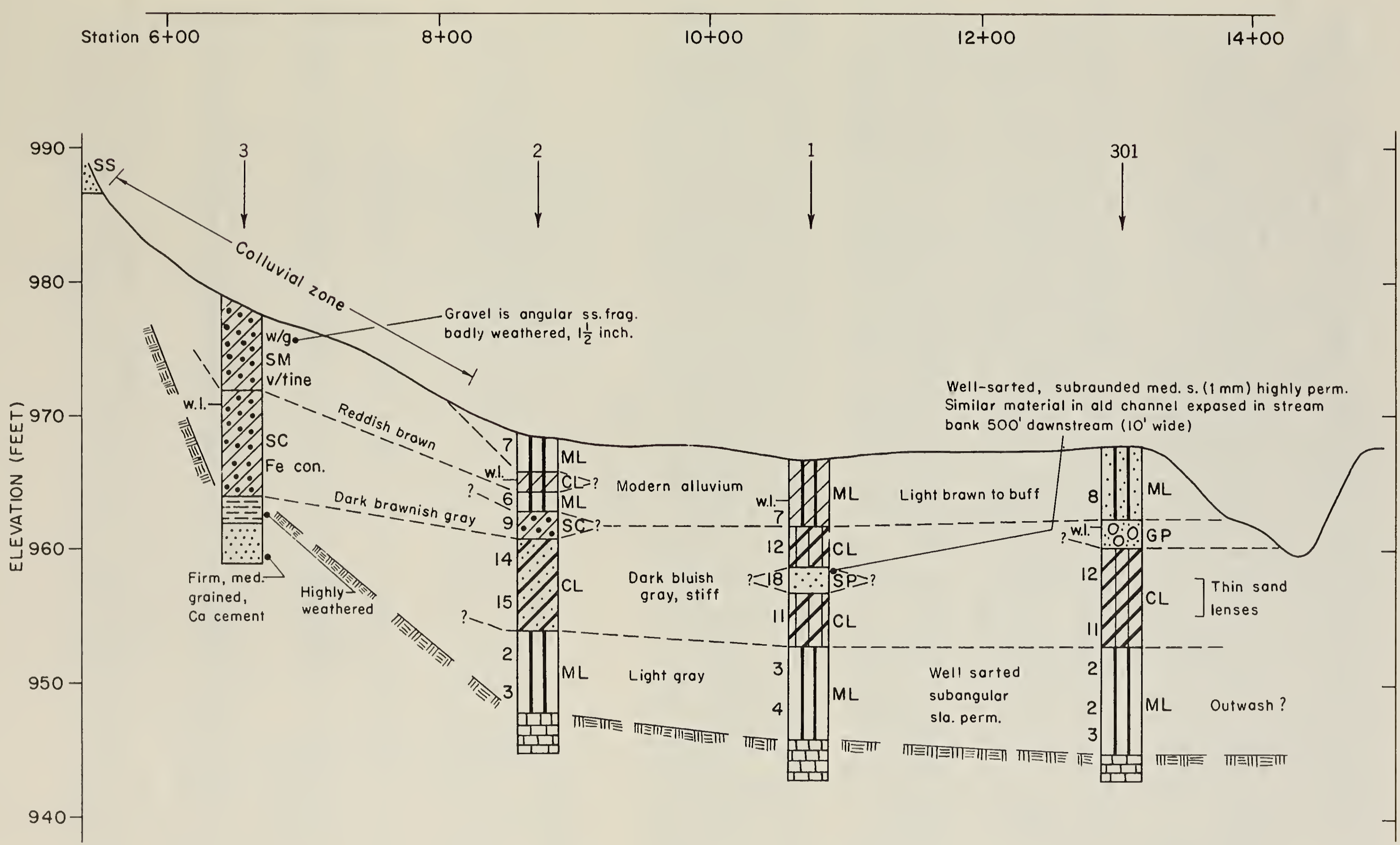


Figure 4-1.--Example of a geologic profile.

Distribution of Graphic Logs and Profiles

When a penciled draft of a field sheet is completed and checked, copies must be reproduced for various purposes. This can be done by blueline printing or photostating locally in the field or in the Cartographic Unit. Copies are needed for the geologic report, a copy of which is to go to the Engineering and Watershed Planning (EWP) Unit geologist and other copies are to accompany the design data to EWP Unit and State Design Sections. Additional copies may be needed for the geologist's files and for distribution to personnel within a State.

When samples are sent to the Soil Mechanics Laboratory or to the EWP Unit Materials Testing Section for analysis, the laboratory needs one transparency and one working copy, either blueline print or photostat, of the field sheet. These must be submitted as soon as the samples are sent to avoid delay in soil mechanics analysis and interpretations. If these copies cannot be obtained locally, send the field sheets to the Cartographic Unit and ask them to prepare the required copies and to forward them immediately to the Soil Mechanics Laboratory or the EWP Unit Materials Testing Section, or both. Send a copy of the transmittal letter to the head of the EWP Unit and a copy to the Soil Mechanics Laboratory. At this time, indicate the number of copies needed by the geologist.

The final drafting of plans and profiles, if they are to accompany final construction plans and specifications, usually is done by the Design Section serving a State. The copy of plans and profiles attached to the geologic report accompanying the design data can be used for this purpose. Lumarith stickups of standard geologic symbols are stocked in the various Cartographic Units to facilitate final drafting of plans and profiles.

Written Logs

Form SCS-533

For written logs for engineering purposes, use form SCS-533, Log of Test Holes, and form SCS-533A, Continuation Sheet. These logs are prepared from field notes and are limited to factual items. These detailed logs include common narrative descriptions of the material. Use terms that can be easily understood.

Form SCS-533 provides space for the test hole No., location, and surface elevation. Several logs may be shown on each sheet of form SCS-533. Where natural outcrops, streambanks, and gullies are used for logging and sampling, determine the elevation of the top of the outcrop and the location of the outcrop.

For "Hole Depth" show the depth in feet from the surface (0.0) to the bottom of the first stratum, or the depth from top to bottom of any underlying stratum.

The description of materials should be complete, clear, and concise. Give the geologic designation that corresponds to the standard pattern used on the graphic log first and underline it, for example, Gravel, silty.

If they can be identified by eye, describe individual particles by size, shape, and composition. Include the approximate diameter of the average maximum-size particle. If possible, indicate the relative proportion of gravel, sand, silt, and clay. Describe particle shape by such terms as angular, subangular, and rounded. Note the principal constituents of the larger particles, such as gneiss, limestone, granite, sandstone, and quartz. Indicate the presence of diatoms, gypsum, iron oxides, organic matter, platy minerals such as micas, and other materials that have an influence on engineering properties. Record color, consistency, and hardness. For fine-grained soils, note relative plasticity, dry strength, and toughness. Indicate the relationships shown by stratification, for example, "varved clay," "interbedded sand and gravel." Indicate the presence of joints and their kind, spacing, and attitude if they can be determined. Indicate consistency or degree of compactness of the materials. Record the standard blow count. Where possible, note the genesis, such as alluvium, lake deposits, and till.

For consolidated rock, include kind of rock, degree of weathering, cementation, and structural and other features in the description. Include the geologic name and age of the formation if it is known. Use the scale of rock strength (chapter 1) to describe the ease of excavation.

Show the Unified soil classification symbol as determined by field tests.

A column is provided for a description of the type and size of tool used for sampling or advancing a hole. Examples are bucket auger, Shelby tube, stationary-piston sampler, double-tube soil-core barrel (Denison type), or double-tube rock-core barrel. The abbreviations[1] that should be used for the different types of samplers are given in the following list.

Bucket auger..................................	BA
Thin-wall open-drive (Shelby)................	S
Split-tube sampling spoon....................	SpT
Stationary piston............................	Ps
Piston (Osterberg type)......................	Pf
Dry barrel...................................	DB
Double-tube soil-core barrel (Denison).......	D
Single-tube rock-core barrel.................	RCs
Double-tube rock-core barrel.................	RCd
Hand cut.....................................	HC

Columns are provided for sample data. It is important to show the sampling horizon and whether the sample is "disturbed" (D), "undisturbed" (U), or "rock core" (R). Show the sample recovery ratio (S), which is equal to L/H where L is the length of sample recovered and H is the length of penetration, as a percentage. Thus, if the sampler penetrates a distance of 18 inches and the sample contained therein amounts to 16 inches,

[1] Show OD size after the abbreviation, as D-5 for 5-inch Denison.

$(S) = \frac{16}{18} \times 100 = 89$ percent. This may be an important factor in the determination of fissures, cavities, or soft interbedded materials in consolidated rock.

Distribution

Distribution of completed written logs is to be the same as that for graphic logs. In copying written logs, make enough carbon copies to supply distribution needs.

CHAPTER 5. REQUIREMENTS FOR GEOLOGIC INVESTIGATIONS AND SAMPLING

CONTENTS

CHAPTER 5. REQUIREMENTS FOR GEOLOGIC INVESTIGATIONS AND SAMPLING

Requirements for design and construction vary widely depending on such conditions as size and purpose of the structure, kinds of construction materials, site conditions, and economic and safety considerations. Geologic site investigations and soil mechanics tests are geared to requirements for design and construction. Hence the procedures and intensity of investigation and the kinds of samples taken vary from site to site. This chapter outlines the requirements for preliminary and detailed site investigations and sampling and also the minimum requirements for intensity of study and for sampling for soil mechanics tests.

Intensity of Site Investigations

Before beginning specific site studies, the geologist should make a reconnaissance survey of the watershed or general area to become familiar with the general geologic situation. He should then make a preliminary geologic investigation of all structure sites to determine geologic conditions and characteristics of materials (both consolidated and unconsolidated) pertinent to design. This should be done regardless of purpose of the structure, source of funds, or contractor. Detailed subsurface exploration or the collection and testing of samples may not be necessary for small, no-hazard structures, such as farm ponds, drop structures, or chutes, to be built in areas of generally homogeneous materials. For these structures, the engineering characteristics of the material at the site need only to be recognized and evaluated on the basis of experience in the area.

Geologic Reconnaissance

Before starting specific site studies, the geologist should become familiar with the general geologic conditions of the area. This can be done by reviewing available data, by examining topographic and geologic maps, and by making a reconnaissance survey. Data gathered during the reconnaissance are primarily descriptive and should include the items in the following list.

1. General geology of possible dam sites.
2. Geologic conditions that may affect channel stability and improvement.
3. Geologic conditions that may influence ground-water movement and recharge.
4. Ground-water conditions.
5. General character of streams and valleys, including steepness of grade and side slopes, bed material, and whether the stream is aggrading or degrading.
6. General availability of suitable construction materials.

Preliminary Site Investigation

The geologist should make a preliminary or surface examination of every site where a structure is planned. This investigation should

include a thorough inspection of outcrops, cut banks, and other surface exposures and an examination of erosion conditions, landslides, seeps, springs, and other pertinent conditions in and adjacent to the watershed to obtain the basic information needed to evaluate the geologic conditions and the character of materials at the site.

The purpose of the preliminary investigation is to determine the geologic feasibility of the site and the extent of detailed subsurface investigation that will be required and to furnish the engineer with enough information to make sound cost estimates. At some sites, the preliminary investigation may furnish enough data on geologic conditions and engineering characteristics of materials for design purposes.

Detailed Site Investigation

A detailed site investigation is made to determine the geologic conditions and to provide the engineer with information for use in design and construction. Usually, detailed subsurface investigations require separate scheduling of equipment such as backhoes, dozers, power augers, and core drills.

Detailed subsurface investigations must be of sufficient intensity to determine all the conditions that may influence the design, construction, and functioning of the structure. The extent of geologic investigation required for a particular dam site depends on (1) complexity of site conditions, (2) size of the structure, (3) potential damage if there is structural failure, and (4) purpose of the structure.

Detailed exploration consists of two phases: (1) Determining and interpreting subsurface conditions and (2) taking samples for soil mechanics tests.

During phase 1, test holes must be put down and logged in the foundation, emergency spillway, and borrow areas. These test holes must be deep enough to insure penetration of all pertinent materials. The number and spacing of test holes must be adequate for correlation in both longitudinal and transverse directions and to the distance needed for complete interpretation of any condition that may influence the design of the structure. Geologic structural features, such as faults, folds, and joints, must be identified and located. Enough information must be obtained on unconsolidated deposits to classify them genetically and to determine their location, thickness, and extent. Test holes can be put down by drilling or by excavating open pits or trenches. Where drilling methods are used, the standard drop-penetration test (blow count) is to be made in cohesive foundation materials below the water table and in noncohesive materials where practical. This test provides a measure of the resistance of the material to penetration by the sampler and also furnishes samples of the material penetrated for identification, classification, and logging. The test is used to evaluate in-place density of the materials. Additional in-place field tests are to be made where needed.

In phase 2 of the detailed site investigation, the data gathered in phase 1 are analyzed on site and the behavior characteristics and engineering significance of the materials and conditions logged are evaluated. From this analysis and evaluation the geologist and engineer determine what materials are to be sampled and what laboratory analyses are needed. This determines the kind, number, and size of samples needed. The necessary samples are obtained by using appropriate sampling procedures. Any additional or special in-place field tests that are needed should be made.

Classification of Structure Sites for Geologic Investigation

Engineering Memorandum SCS-33 (Rev. 1960) establishes the following broad groups of structure sites to permit the association of minimum requirements for geologic investigations with maximum fill height of the proposed dam, construction materials, purpose of the structure, and the damage that might result from a sudden major breach of the earth-dam embankment (Engineering Memorandum SCS-27).

Group I Dam Sites

This group includes proposed sites for--

a. All class (c) dams.
b. All class (b) dams.
c. All dams with maximum fill height of 35 feet or more not included in class (b) and class (c).
d. All structures of the following types more than 20 feet high: Concrete or masonry arch or gravity dams, drop spillways, box-inlet drop spillways, and chutes.
e. All dams with maximum fill height of more than 20 feet where the principal purpose is forming storage reservoirs for recreation, municipal water supply, or irrigation and where the product of the storage times the height of the dam is more than 3,000.

Group II Dam Sites

This group includes proposed sites for--

a. All dams not included in class (c) or class (b) with maximum fill height of 25 to 35 feet.
b. All structures of the following types with maximum height of 10 to 20 feet: Concrete or masonry arch or gravity dams, drop spillways, box-inlet drop spillways, and chutes.
c. All dams less than 20 feet high where the principal purpose is creating storage reservoirs for recreation, municipal water supply, and irrigation and where the product of the storage times the height of the dam is between 1,000 and 3,000.

Group III Dam Sites

This group includes proposed sites for--

a. All other types of dams not included in groups I and II.

Minimum Requirements for Geologic Investigations

The following criteria establish the minimum site investigation that will provide an acceptable basis for design and construction. In establishing the intensity of investigation for the following classifications, give full consideration to past experience in the area and to the degree of geologic heterogeneity.

Group I Dam Sites

All sites in this group should be investigated by a qualified geologist. This applies to the preliminary investigation as well as the detailed study and subsurface exploration. For all such sites, subsurface exploration must be of sufficient intensity to permit the determination of:

1. Depth, thickness, continuity, relative permeability, and other pertinent characteristics of all materials to the specified depth beneath the base area of the dam and the centerline of any proposed outlet structure.
2. Attitude, location, extent, and character of such geologic features as folds, faults, joints, unconformities, schistosity, slaty cleavage, bedding planes, and bedrock surface.
3. Extent and character of the unconsolidated and consolidated rock materials to be removed from the emergency or other open spillway and character and stability of the material in which this spillway is to be constructed.
4. Depth, thickness, continuity, distribution, and engineering properties of the material proposed for use as fill.
5. Depth to ground water and extent and character of aquifers.

To attain these objectives, use the following guide for the <u>minimum</u> number and the <u>minimum</u> depth of holes (including pits or trenches) that will provide the necessary information. Usually, these minimums are adequate only for the most favorable geologic conditions.

The depth of borings or pits along the centerline of earthfill dams is to be <u>no less than</u> the proposed height of fill unless unweathered rock is encountered. The minimum depth of borings in compressible materials, where the influence of surface load is significant to depths greater than the height of the dam, is to be determined jointly by the geologist and engineer. For all concrete dams, the depth of borings is to be no less than 1.5 times the height of the controlled head of the dam unless unweathered rock is encountered.

Extend borings far enough into unweathered rock to determine its nature and condition. All borings are to be deep enough to establish correlation with adjacent holes so that a complete geologic section can be obtained from the elevation of the top of the proposed fill to that of the bottom of the deepest bore hole. Determine the ground-water elevations in the foundation throughout the base area of the dam and abutment. The number and the spacing of holes needed depend mostly on such geologic features as regularity, continuity, and attitude of strata and character of geologic structures. Ordinarily, there should be at least five borings along the centerline of the dam.

For drop-inlet spillways or other pressure conduits used as outlet structures, put down borings on the centerline of the outlet structure (1) at the intersection with the centerline of the dam, (2) beneath the proposed location of the riser,

and (3) beneath the downstream toe of the dam. Where rock occurs close to the conduit foundation, the investigation must accurately delineate the rock surface below the centerline of the conduit. The minimum depth of holes along the centerline of the outlet is to be either equal to the height of the proposed fill over the outlet conduit at the location of boring or 12 feet, whichever is greater, unless unweathered rock is encountered. The minimum depth of borings below the riser is to be either equal to the estimated height of the riser or 12 feet, whichever is greater.

For other types of spillways, such as drop spillways and chutes, enough borings must be made and samples obtained for analysis to permit designing a structure that will be safe insofar as bearing and sliding are concerned.

Where an excavated emergency spillway is planned, investigations must be of sufficient intensity to determine quantity and character of the materials to be excavated, limits of common and rock excavation, suitability of the excavated material for use in construction, and erodibility of the resulting spillway channel. Each boring for emergency-spillway investigations must extend to a depth of not less than 2 feet below the bottom of the proposed emergency spillway.

Enough borings must be made in the borrow areas to identify and establish the distribution and thickness of all materials to be used for fill. All borrow-area borings should extend at least 2 feet below the expected depth to which material is to be removed unless consolidated material that is not suitable for fill is found. Determine the depth to ground water at the time of boring for all borrow-area borings.

Hydraulic-pressure tests are to be made if leakage is suspected in rock foundations or abutments of proposed dams forming storage reservoirs. This test consists of a holding test of not more than 1 p.s.i. per foot of depth below ground surface, followed by a pumping test if the pressure drop in the holding test exceeds 10 p.s.i. per minute (chapter 2).

<u>Group II Dam Sites</u>

A geologist is to make the preliminary site investigation and to determine what is needed in the way of a detailed site study.

The intensity of subsurface exploration and sampling needed for sites of the larger structures in group II is similar to that for group I sites. General experience in the area, present geologic information, and the preliminary geologic examination, however, may provide enough information so that a less intensive program of subsurface exploration and sampling will suffice for the sites of smaller structures in this group.

<u>Group III Dam Sites</u>

The intensity of investigation needed for group III structure sites can usually be determined by persons holding positions to which job-approval

authority for the class of structure under consideration has been delegated by State memorandum. In areas where there is little or no experience on which to base conclusions and in areas where geologic conditions are complex, a geologist should be consulted. A geologist is to investigate those structure sites in group III that require the technical approval of the head of the EWP Unit.

For very small structures, the economic feasibility of site studies must be considered. Weigh the cost of such studies against the cost of the structure and the possible adverse effects of structural or functional failure.

Minimum Requirements for Sampling of Dam Sites

The intensity of sampling needed, like the intensity of site investigations, varies with design requirements. Thus the minimum sampling requirements can be coordinated with the various dam-site groups established to determine the intensity of geologic investigation needed.

Group I Dam Sites

It is essential that adequate samples be obtained both for field examination and for testing and analysis by a soil mechanics laboratory. This usually means taking both undisturbed and disturbed samples of unconsolidated materials and in some places obtaining rock core samples.

For all sites in group I, representative samples for classification purposes should be taken of all types of materials in the borrow, foundation, relief-well, and spillway sections.

For all sites in groups Ia, Ib, and Ic, samples for compaction and shear tests should be taken from the borrow and emergency-spillway areas. For sites in groups Id and Ie, samples for compaction tests should be taken from the borrow and emergency-spillway areas if there is not enough information or experience in the area to definitely determine the behavior of materials.

For all sites in groups Ia, Ib, and Ic and for the sites of all dams more than 25 feet high in groups Id and Ie, undisturbed samples for shear tests should be taken from all strata of fine-grained soils of questionable stability in the foundation within a depth equivalent to one-half the height of the dam.

For all sites in groups Ia, Ib, and Ic, undisturbed samples for consolidation tests should be taken of all fine-grained materials of questionable stability within a depth equivalent to the maximum height of the dam. Where compressible materials extend to depths greater than the height of the dam, the depth from which such samples should be taken must be increased. For sites in groups Id and Ie, such samples are also to be taken of questionable materials of low shear strength, such as soft clays and soft silts, in the foundations of dams more than 25 feet high.

For sites in group I, samples for chemical analysis should be taken of all water supplies to be used for construction of the embankment or of concrete appurtenances if it is suspected that the water contains a high concentration of salts (particularly sulfates and alkalies) or of humic and other acids that have a deleterious effect on construction materials.

For all sites in group I, samples should be taken of all materials proposed for stabilization by soil cement or chemical methods.

For all sites in group I, samples should be taken of reservoir and abutment materials to determine reservoir-sealing requirements if storage (other than sediment-pool storage) is to be incorporated in the design and if moderate or serious leakage is suspected.

Group II Dam Sites

For all dam sites in group II, representative samples for classification purposes should be taken of all types of materials in the borrow, emergency-spillway, foundation, and relief-well sections.

For all sites in group IIa, samples for compaction tests should be taken from the borrow and emergency-spillway areas.

For all sites in group II, undisturbed samples for shear tests are required if questionable materials of low shear strength are encountered. Soft clays and silts that develop low shear resistance because of the nature of particles are included. Usually undisturbed samples are not required for shear tests of foundation materials of dams less than 25 feet high.

Samples for consolidation tests are required under the same conditions as those outlined for shear tests. If compressible materials are encountered, samples may be needed from depths greater than the equivalent height of the dam.

The sampling requirements for permeability tests, water analyses, soil-cement tests, and reservoir-sealing tests for dam sites in group II are the same as for dam sites in group I.

Group III Dam Sites

For dam sites in group III, samples for laboratory analysis are not usually necessary if adequate information and experience is available in the area on which to base conclusions. Where such information is not available or if highly questionable conditions are found, sampling may be necessary.

CHAPTER 6. PRELIMINARY SITE INVESTIGATION

CONTENTS

CHAPTER 6. PRELIMINARY SITE INVESTIGATION

Soon after a dam site has been tentatively selected, the geologist makes a preliminary investigation of the site. This consists of a field study and a review of available literature and maps relating to regional geology and physiography. For watershed protection projects (Public Law 566), this preliminary investigation is usually made in the work-plan stage to obtain information needed to determine both physical and economic feasibility.

The geologist and the engineer must work together closely during the preliminary site investigation. They should discuss geologic conditions that may influence the design, construction, cost, and functioning of the proposed structure. Where these conditions appear adverse, a more intensive investigation may be required to determine site feasibility.

Purpose

The purpose of a preliminary site investigation is to establish the geologic feasibility of the site and to determine the extent and precision of detailed subsurface investigation required to obtain the information needed for design and construction. For some sites the preliminary investigation, together with experience in the area, may be adequate to determine the geologic conditions and the engineering characteristics of materials. At other sites enough information on subsurface materials can be readily obtained during the preliminary examination from test pits, hand-auger borings, trenching, or other methods so that a detailed subsurface investigation is not required. But a detailed subsurface investigation must be scheduled where enough information for design cannot be obtained with the tools available during the preliminary examination. Then the results of the preliminary examination provide a basis for planning the detailed investigation. This planning requires consideration of such items as depth, number, and location of borings; kinds and locations of samples to be taken; equipment required; requirements for clearing, staking, and mapping the site; and need for access roads.

Assembly of Data

Before beginning a field study of a site, review the available geologic, physiographic, and engineering-experience data. The usual sources of reference data are publications of the U.S. Geological Survey; State geological surveys; U.S. Department of Agriculture soil survey reports; special reports and papers in scientific publications; and Federal, State, or local engineering-experience information where available. A base map on a usable scale, topographic sheets, aerial photographs, and geologic and soil maps are also helpful. Preliminary information on the location of the proposed dams is essential. The following site information is needed.

1. Purpose of dam and reservoir.
2. Estimates of height of dam and cubic yards of compacted fill required.

3. Estimated maximum and normal pool elevations.
4. Class of structure (see Engineering Memorandum SCS-27).
5. Approximate area in reservoir basin.
6. Approximate location of emergency spillway.
7. Approximate location of outlet structure.

Geologic and topographic maps are useful for determining the general geology, and soil maps are helpful for the general delineation of boundaries of particular kinds of surface materials.

Wherever possible, the geologist should make use of the general design and construction experience and the performance of structures in the area. Interviews with engineers or other technicians familiar with the design and operation of these structures and visits to structures under construction are particularly helpful in areas where the geologist has had little or no experience. Available reports on laboratory analyses of local materials should be reviewed to determine physical and engineering properties for possible application to the site in question.

Use of Aerial Photographs

A study of aerial photographs of the general area of the site is helpful. Color tone, vegetation, landforms, and drainage patterns often are indicators of geologic features, including kinds of rock, fractures, sinks, and landslides, and of moisture and soil conditions. Stereoscopic prints provide three-dimensional impressions that help in establishing the general geology during subsequent field studies.

Tones in a photograph and vegetative pattern can indicate moisture conditions or differences in the kind of soil or rock. Very dark tones may indicate water close to the surface and very light tones, low surface moisture. Sands and gravels tend to produce light tones, whereas fine-grained soils produce darker tones. A change in vegetative pattern may indicate a change in kind or texture of soil or rock.

Since landforms are the result of geologic processes, their identification may give some indication of geologic structure as well as of soil and rock materials. Drumlins, eskers, outwash and alluvial fans, talus cones, landslides, slumps, sinkholes, and abrupt changes in slope are some of the landforms that can be recognized.

Drainage patterns may be indicative of surface materials, topography, and geologic structure. A radial pattern in which streams flow outward from a center indicates an uplifted dome or a volcanic cone. A dendritic or treelike pattern typically develops on horizontally bedded rock. A parallel pattern implies a uniform slope such as a coastal plain. A rectangular or lattice pattern characterized by right-angle bends in both the main stream and its tributaries indicates structural control from joints or faults. A trellis pattern, also characterized by right-angle bends and junctions but more regular than a rectangular pattern and having main streams and their larger tributaries parallel, is also due to structural control and is typical of steeply dipping or tightly

folded sediments. An annular or ringlike pattern is due to rock structure and is usually associated with maturely dissected dome or basin structures.

In addition, local interruption or modification of drainage, such as a stream pushed to one side of the valley, overfalls, swampy conditions, incised meanders, braided streams, and oxbow lakes and abandoned or buried channels, may be helpful in interpreting the conditions at the site.

Delineate any features of tone, vegetation, landform, and drainage on the aerial photographs or on overlays for subsequent checking in the field.

Field Study

A field study of the site and the surrounding area should include a traverse of the valley for about a mile above and a mile below the site. It should include a study of slopes, tributary valleys, landslides, springs and seeps, sinkholes, exposed rock sections, and the nature of unconsolidated overburden to obtain information on the general geology of the area. An inspection of upland and valley slopes may provide clues to the thickness and sequence of formations and to rock structure. The field study should also include inspections of the shape and character of channels and the nature of residual, colluvial, alluvial, fan, slide, and other kinds of deposits. Any observations of ground-water occurrence, especially in alluvial deposits, should be recorded. Possible sources and approximate amounts of borrow material should be noted. A few hand-auger borings or test pits may be needed.

The geologist should make a thorough inspection of the dam and reservoir area. He should identify and describe all geologic formations visible at the surface and note their topographic positions. He should determine the local dip and strike of the formations and note any stratigraphic relationships or structural features that may lead to problems of seepage, excessive water loss, and sliding of the embankment.

He should locate and delineate any faults. If they are numerous, active, or of large displacement, it may be necessary to relocate the dam or the principal spillway. In addition to other problems, faults and fault zones may cause serious leakage.

Hand-auger borings or test pits may be needed for some preliminary exploration at the dam site. If power tools are available, they should be used if conditions warrant. If there are geologic conditions that indicate that the site may not be feasible, they should be thoroughly investigated immediately.

Depth to ground water, depth to bedrock, thickness of recent alluvium and colluvium, and availability of suitable borrow material are conditions that may require further definition.

Mapping

It is always advisable to prepare a geologic map of the site. Use the best available base map or aerial photograph. Plane-table surveys may be needed. Features to be shown on the map include --

1. Areal geology of all surface formations, including delineation of unconsolidated deposits.
2. Texture of surficial deposits.
3. Structure of bedrock, including dip and strike, faults or fractures, stratification, porosity and permeability, schistosity, and weathered zones.
4. Ground-water features, including seeps, springs, observable water tables, and drainage.
5. Areas of modern deposits (result of accelerated erosion).
6. Unstable slopes, slips, and landslides.

Report of Preliminary Investigation

Prepare a report of the preliminary geologic investigation and make recommendations on the need for further investigation.

Form SCS-375, Preliminary Geologic Examination of Dam Sites, may be used. Use form SCS-533, Log of Test Holes, to record information obtained from any power drilling, test pits, or hand augering. Send one copy of both forms to the EWP Unit engineering geologist. This information is useful in planning a detailed subsurface investigation if one is necessary. Since form SCS-375 is for in-Service use only, its distribution should be restricted to SCS personnel.

In some situations the preliminary site investigation and knowledge and experience in the area provide enough information for design purposes without further detailed investigation. Thus for small structures in areas where site conditions are not complex and where there is little variation in conditions or materials from one site to the next, previous investigations in the general area may be applicable. For these sites prepare forms SCS-35A, - 35B, and -35C from the hand-auger data and submit them with the report. If samples from other sites with similar conditions have been analyzed and the data are used as criteria in preparing the recommendations, include in the report a reference to these samples and note the availability of the data.

For those sites where previous information permits a preliminary investigation to be used for design, it is necessary to locate and delineate borrow areas. This can be done only by subsurface exploration. A detailed investigation must be made of all borrow areas.

CHAPTER 7. DETAILED SITE INVESTIGATION

CONTENTS

TABLES

CHAPTER 7. DETAILED SITE INVESTIGATION

A detailed site investigation provides information on subsurface conditions that cannot be obtained by surface examination or by shallow subsurface investigation in which readily portable tools such as hand shovels and hand augers are used. Usually, detailed subsurface investigations require equipment such as backhoes, dozers, power augers, or core drills.

Detailed site investigations are required if information about the geology of the area is not adequate or if the results of the preliminary geologic examination are not sufficiently conclusive to positively establish that:

1. Knowledge of the foundation materials and conditions to a depth at least equal to the height of the proposed structure is of sufficient scope and quality to serve as a basis for geologic interpretation and structural design.
2. Fill materials of suitable quality are available in sufficient quantity.
3. The reservoir basin of storage reservoirs is free from sinks, permeable strata, and fractures or fissures that might lead to moderate or rapid water loss.
4. Subsurface water conditions that might materially affect the design of the structure or the construction operations are known.
5. Stability characteristics of material in the emergency or other open spillways and channels under anticipated flow conditions during operation of the structure are known.
6. The probable rate of sedimentation of the reservoir will not encroach upon the usable storage capacity in a period of years less than the designed life expectancy of the structure.

Detailed subsurface investigations must be of sufficient intensity to determine all the conditions or factors that may influence the design, construction, or functioning of the structure.

Subsurface investigations of dam sites are made after the surface geology has been studied. The nature and intensity of underground exploratory work for a particular type and purpose of structure are conditioned by this earlier examination of the area. As subsurface work progresses, the findings may further modify the intensity of investigation needed. Other conditions being equal, the intensity of investigation depends on the complexity of the site.

It is desirable for the operations geologist to inspect dam sites during construction to get a better understanding of construction procedures, to observe subsurface conditions that are exposed, and to confer with the engineer on any problems involving geology that develop.

Detailed subsurface investigations can be carried out under contract with local companies or by SCS personnel using SCS-owned equipment.

Contracting for Geologic Investigations of Dam Sites

In those States where the annual workload is not large enough to justify the purchase of drilling equipment, drilling services must be obtained for subsurface investigations by arrangement with other States or by contracting with private companies. These services may be obtained by (1) equipment-rental contract or (2) inclusion in a negotiated engineering contract for professional services (see Engineering Memorandum SCS-36). If an equipment-rental contract is let, logging and classifying materials, developing interpretations, and preparing the reports are the responsibility of SCS personnel. In a negotiated engineering contract for geologic investigations, the contractor is required to provide and operate exploration equipment, to log and classify the materials, and to prepare the geologic report. A negotiated engineering contract can be let solely for geologic investigations including analysis and reports, or these investigations can be included in an overall contract that also includes laboratory analysis and development of the final design.

Minimum requirements and technical standards for SCS work are the same for contracted work as for work done with SCS owned and operated equipment.

Preparation for Subsurface Exploration

Assembling Maps, Reports, and Basic Data

Available geologic information may indicate the intensity of investigation needed. Review the data collected during the preliminary geologic examination and the report of that examination in detail. This study may indicate the extent to which additional information and data are needed. The sources of information suggested under Assembly of Data in chapter 6 may furnish more data on problems that may be present.

Before the field work is started, the engineering-survey information and any available preliminary design data should be plotted on forms SCS-35A, -35B, and -35C so that the geologist can locate and log the test holes and correlate between them.

The preliminary plan of the proposed structure, including the centerline of the dam and the proposed centerline of the principal outlet structure and emergency spillway, the present stream channel, and a map of the proposed borrow area(s) containing grids or traverse reference are prepared on form SCS-35A. Cross sections of the borrow area are to be drawn on this sheet as the investigation proceeds.

The profiles of the proposed centerline of the dam and the principal spillway are prepared on form SCS-35B. If cross sections of the stream channel are needed, they are to be plotted on this sheet as the investigation proceeds.

Form SCS-35C includes the proposed centerline of the emergency spillway and provides space for the cross sections of the emergency spillway that

are developed during the course of the investigation. If needed, form SCS-315 may be used for additional profiles and cross sections, such as the profile in the downstream part of the dam if borings are needed for toe drains or relief wells.

Necessary Authorizations

It is essential always to obtain the landowner's permission to enter, cross, and exit from his land or property. Permission is also required if property is to be removed (temporarily or permanently), displaced, or rearranged. Permission is required for construction of roads, sumps, ditches, or ramps; for use and discharge of water belonging to the property owner; for construction of exploratory trenches, auger holes, drill holes, and test pits; and for stream displacement or obstruction. The necessary clearance is to be obtained by the Work Unit Conservationist.

Preparation of Site

If the activities of the survey crew and the investigation party are well coordinated, the dam and reservoir areas should be mapped, staked, and adequately cleared before equipment for subsurface investigation arrives.

Staking and Clearing

Locations of the centerline of the dam, centerline of the principal spillway, and cross sections of the emergency spillway should be staked. In many cases it is desirable to survey and stake an alternate location for the principal spillway. In areas of tall grass or weeds, lath and flagging should be used to locate the stakes.

All grid lines in the borrow area, emergency-spillway cross sections, centerline of the principal spillway, and centerline of the dam should be cleared to a width sufficient to provide easy access for the drilling equipment. If a stream crossing must be provided, it may have to be located upstream from the reservoir to avoid modifying the ground-water conditions at the site.

Subsurface Exploration
Phase 1: Geologic Correlation and Interpretation

Purpose and Objectives

The purpose of phase 1 of the detailed subsurface investigation is to identify, delineate, and correlate the underlying materials; to locate, identify, and interpret geologic features; to determine ground-water conditions; to interpret, to the extent possible by field tests, the engineering properties of the materials; and to determine what materials need to be sampled for soil mechanics tests.

Split-tube or thin-wall drive samplers are recommended for exploratory boring. For accurate logging of unconsolidated thin-bedded and highly variable materials, thin-wall or split-tube drive samplers must be used. Thin-wall drive samplers can be used for this purpose only if the drilling rig is equipped with a suitable device for extruding samples.

The number, distribution, and size of test holes and the number of samples needed to establish subsurface conditions vary widely from one investigation to another, depending on the variety and complexity of the conditions. Enough test holes of adequate depth must be bored for the geologist to identify, delineate, and correlate the underlying strata and for the engineer and the geologist to determine the kinds and locations of samples needed. Where experience or previous examination indicates that only shallow test holes are needed, the excavation of open pits with hand tools or dozers and backhoes may be adequate. Where there are numerous cobbles and boulders, backhoe or dozer pits may be the most practical method of exploration. Where pits and trenches in the foundation area cannot be left open, record their location and extent accurately and show them on the plan so that, if necessary, they can be reopened and properly sloped and backfilled during construction.

Numbering Test Holes

Use the following standard system of numbering test holes.

Location	Hole Nos.
Centerline of dam	1-99
Borrow area	101-199
Emergency spillway	201-299
Centerline of principal spillway	301-399
Stream channel	401-499
Relief wells	501-599
Other	601-699
Other	701-799, etc.

Principal-spillway, channel, and emergency-spillway holes that are on the centerline of the dam should be given principal-spillway, channel, and emergency-spillway Nos. rather than centerline-of-dam Nos. Number foundation holes in the area of the base of the dam but not in the immediate vicinity of the centerline of the dam or appurtenances as "other."

Determining Location and Depth of Proposed Test Holes

Make exploratory borings along the centerline of the dam, along the centerline of the outlet structure, in the spillway area, and in the borrow area or areas. Additional exploratory borings will be needed if relief wells or foundation drains are required or if special information is needed because of site conditions.

Foundation test holes.--Centerline investigations must determine whether there is stable support for the dam; whether all strata have enough strength to prevent crushing, excessive consolidation, or plastic flow; and whether water movement through the foundation or abutments will cause piping, detrimental uplift pressure, or excessive water loss.

Conditions that must be recognized and located include nature, extent, and sequence of strata; highly dispersed soils; soluble salts; aquifers; and any weak bedding planes, joints, faults, or other structural weaknesses in the underlying formations.

The spacing and number of test holes needed along the centerline of the dam or beneath the proposed base depend principally on the complexity of the geology. Some of the more important factors are character and continuity of the beds, attitude of the strata, and presence or absence of joints or faults. Depth, thickness, sequence, extent, and continuity of the different materials must be determined.

A convenient system of boring to determine site conditions is to locate one test hole on the flood plain near each abutment and one on the centerline of the outlet structure. Between these holes additional holes may then be located as needed to establish good correlation of strata. At least one hole should be put in each abandoned stream channel that crosses the centerline. At least one hole is usually required in each abutment unless a good surface exposure is available. It is highly important that enough investigation be carried out to establish continuity of strata, or the lack thereof, throughout the area underlying the base of the proposed dam.

In addition to the minimum requirements for depth of exploration set forth in chapter 5, the following criteria apply to foundation investigations.

Investigations must proceed to a depth of not less than the height of the dam unless unweathered rock is encountered. For this purpose rock is interpreted as indurated, virtually incompressible material that is not underlain at least for a depth equal to the height of the dam by unstable, compressible materials. Usually rock includes shale and siltstone. Experience and knowledge of the general stratigraphy of the area may provide information on the thickness of these rock formations. The lack of positive information about the formations makes it necessary to drill an exploratory hole to the "minimum" depth specified, as if the formation were unconsolidated material.

Where compressible material extends to a depth equal to the maximum height of the dam, it may be necessary to extend exploration to a much greater depth. Depth of exploration depends on the character of material and on the combined pressure exerted by overburden and embankment. Tables 7-1 and 7-2 will help the engineering geologist to make this decision. Table 7-1 shows the approximate loading values of earthfill structures of various heights of fill at various depths. For example, a dam 50 feet high exerts a downward pressure of about 1.9 tons per square foot at a depth of 50 feet directly below the centerline of the dam. This is only an approximate value because load varies with density of the fill material, shape and rigidity of the dam, and strength of the foundation material above the point of measurement.

Table 7-2 shows the presumptive bearing values of various unconfined materials for different consistencies and relative densities. These values are the approximate loads to which these various soil materials can safely be subjected without excessive settlement. This is somewhat ambiguous because a given amount of settlement per unit thickness may be of minor significance for a thin layer but excessive for a thick stratum.

The estimate of consistency and relative density must be made from examination of representative samples, blow count, drilling characteristics, or an estimate of the dry density and void ratio of the material.

An example of how to use tables 7-1 and 7-2 follows. The foundation for a dam 50 feet high has been drilled to the minimum depth of 50 feet, and the bottom of the bore hole is still in compressible materials. The approximate vertical stress at this depth from a 50-foot dam is 1.9 tons per square foot (table 7-1). The material at the bottom of the hole is a stiff inorganic plastic clay (CH). Table 7-2 shows that stiff CH has a presumptive bearing value of 1.5 tons per square foot. This indicates that the formation is subject to deformation under the proposed load and that exploration must continue to a greater depth until the vertical stress is equal to or less than the safe load value (in this example at a depth of 85 feet).

Since these are approximate values, use them only as guides for increasing the minimum depth of exploration. Do not use them for design. Never use the tables as justification for terminating exploration at a depth of less than the minimum set forth in chapter 5.

<u>Principal-spillway test holes</u>.--Complete information on the strata underlying the outlet structure is needed to design the outlet structure. It is necessary to determine if there is likely to be appreciable differential settlement that may result in cracking. If the outlet conduit is to be located on or near rock with an irregular surface, the profile of the rock surface must be accurately defined. The number of test holes needed for this purpose depends on the configuration of the rock. If the rock surface is undulating, numerous test holes may be required so that the needed depth of cradle and the treatment of the foundation can be determined. In addition to the test hole at the intersection of the centerline of the dam and other holes needed to determine the configuration of rock, test holes are needed at the proposed riser location, at the downstream toe of the dam, and at the downstream end of the outlet conduit. For other types of outlets exploration requirements vary widely from site to site, but boring must be adequate to permit the design of structures that are safe insofar as bearing and sliding are concerned.

The minimum depth of holes along the centerline of the outlet is to be equal to the height of the proposed fill over the outlet conduit at the location of boring or 12 feet, whichever is greater, unless unweathered rock is encountered. The minimum depth of holes below the riser is to be equal to the difference in elevation between the top of the riser and the natural ground line or 12 feet, whichever is greater.

<u>Emergency-spillway test holes</u>.--It is necessary to determine the stability and erodibility of spillway material and to provide adequate information on the extent and volume of the various types of material to be excavated and on the suitability of the excavated material for use in construction. A series of geologic cross sections at right angles to the centerline of the spillway should be developed if conditions are highly variable or if long spillway sections are planned.

Table 7-1.--Approximate vertical-stress values of earthfill structures weighing 100 pounds per cubic foot[1]

Height of dam (feet)	Depth (feet)																								
	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	110	120	130	140	150
	Tons per square foot																								
5	0.2	0.1	0.1	0.1	0.1																				
10	0.5	0.4	0.3	0.3	0.2	0.2																			
15	0.7	0.6	0.6	0.5	0.5	0.4	0.4	0.4	0.3																
20	1.0	0.9	0.8	0.8	0.7	0.7	0.6	0.6	0.5	0.5	0.5	0.4													
25		1.2	1.1	1.1	1.0	0.9	0.9	0.8	0.8	0.7	0.7	0.6	0.6	0.6	0.6										
30			1.4	1.3	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.6							
35					1.5	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7				
40					1.7	1.7	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.8	0.8	
45					2.0	1.9	1.9	1.8	1.7	1.7	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.3	1.2	1.2	1.1	1.1	1.0	0.9	0.9
50						2.2	2.1	2.0	2.0	1.9	1.8	1.8	1.7	1.7	1.6	1.6	1.5	1.5	1.4	1.4	1.4	1.3	1.3	1.2	1.2
55							2.4	2.3	2.2	2.2	2.1	2.0	2.0	1.9	1.9	1.8	1.8	1.7	1.6	1.6	1.5	1.5	1.4	1.3	1.3
60								2.6	2.5	2.4	2.4	2.3	2.2	2.2	2.1	2.0	2.0	2.0	1.9	1.9	1.8	1.7	1.6	1.5	1.5
65									2.8	2.7	2.6	2.5	2.5	2.4	2.4	2.4	2.3	2.2	2.2	2.1	2.1	2.0	1.9	1.7	1.7
70									3.0	2.9	2.9	2.8	2.7	2.7	2.6	2.6	2.6	2.5	2.4	2.3	2.3	2.2	2.1	2.0	1.9
75										3.2	3.1	3.1	3.0	2.9	2.9	2.9	2.8	2.7	2.7	2.6	2.6	2.5	2.4	2.2	2.1
80											3.4	3.3	3.2	3.2	3.1	3.1	3.1	3.0	2.9	2.9	2.8	2.7	2.6	2.4	2.3
85												3.6	3.5	3.4	3.4	3.4	3.3	3.2	3.1	3.1	3.0	2.8	2.7	2.6	2.6
90												3.9	3.8	3.7	3.6	3.6	3.6	3.4	3.3	3.3	3.2	3.1	3.0	2.9	2.8
95													4.0	4.0	3.9	3.9	3.8	3.7	3.6	3.6	3.4	3.3	3.2	3.1	3.0
100													4.3	4.2	4.2	4.2	4.1	3.9	3.8	3.8	3.7	3.6	3.5	3.4	3.3

[1] Do not use for design purposes.

Table 7-2.--Presumptive bearing values (approximate maximum safe-load values) of soils as related to the Unified soil classification system

Noncohesive materials

Relative density[1]	GW	GP	SW	SP	GM	GC	SM	ML
	Tons per square foot							
Very loose.	--	--	0.50	0.50	0.25	0.25	< 0.25	--
Loose......	1.75	1.75	1.00	1.00	.50	1.25	.75	0.25
Medium or firm.	3.50	3.25	2.25	2.00	1.40	2.40	1.75	1.00
Dense or compact.	5.25	5.00	3.75	2.25	2.80	3.50	2.50	1.75
Very dense or very compact.	6.00	5.75	4.50	3.25	3.50	6.25	3.00	2.00

Cohesive materials

Consistency[1]	SM	SC	ML	CL	OL	MH	CH	OH
	Tons per square foot							
Very soft..	0.25	0.25	--	0.25	--	--	--	--
Soft.......	.50	.50	0.25	.50	--	0.25	0.25	--
Medium.....	.75	1.00	.75	1.00	0.25	1.00	1.00	0.25
Stiff......	1.50	2.25	1.75	2.25	1.00	2.25	1.50	1.00
Very stiff.	2.00	2.75	2.00	2.75	1.50	2.75	1.75	1.25
Hard.......	2.50	3.25	2.50	3.25	2.00	3.25	2.25	1.50

[1] Relative density and consistency as related to standard penetration test (table 2-1).

Initially, one cross section should be located approximately at the control section, one in the outlet section, and one in the inlet section of the spillway. Additional cross sections can then be located as needed for correlation, to locate contacts, or to obtain additional needed data. On each cross section, test holes should be located at the centerline and at the sides of the spillway. Where deep spillway cuts are planned, additional test holes may be needed to determine the character of the material in the sides of the cut. Where there is consolidated rock, it is important to carefully delineate the rock surface. The number of additional cross sections or test holes that may be needed for this purpose depends on the configuration of the rock. Each boring for emergency-spillway investigations must extend to a depth of not less than 2 feet below the bottom of the proposed emergency spillway.

Investigations for rock excavation must be of sufficient detail that the estimate of quantity is no more than 25 percent in error. Boring must extend to a depth of at least 2 feet below the level to which excavation is planned. This usually requires drilling equipment even where delineation of the rock surface has been accomplished by using a bulldozer or backhoe. Carefully log and describe the material to be excavated. Give special attention to such structural features as thickness of beds; attitude, character, and condition of bedding planes; joint systems and attitude and condition of joint planes; schistosity; cleavage; flow banding; and cavities and solution channels as well as to strength (chapter 1) and degree and kind of cementation. These factors influence the method and hence the cost of excavation. Under some combinations of these conditions rock can be ripped and removed, other combinations may require special equipment, and still others blasting.

Borrow-area test holes.--The proposed borrow area is investigated to identify and classify the materials according to their availability and suitability for use in constructing the dam. From these investigations the location and quantities of desirable materials and the areas in which borrow pits may be most conveniently developed can be determined. The location and approximate extent of any undesirable materials must be determined. Depth to ground water, if reached, must be recorded.

The initial location of test holes in the borrow area should be according to some systematic plan, such as intersections of a grid system, so that the area is adequately covered by a minimum number of holes. Additional holes can then be located where they are needed to establish subsurface conditions. All borings should extend at least 2 feet below the expected depth of removal of material unless consolidated material that is not suitable for use is encountered.

Usually about 12 borrow-area test holes will suffice for all but the larger structures, but local topography, geology, and ground-water conditions may require great variation in the intensity of this study.

Reservoir-basin test holes.--Local geologic conditions may require subsurface exploratory work in the general area of the site and reservoir.

The location, number, and depth of these test holes depends on the specific problem to be solved. If the presence of cavernous or permeable strata that may adversely influence the functioning or stability of the structure is suspected, it is necessary to put down enough test holes to determine these conditions in order to develop appropriate safeguards.

Foundation-drain and relief-well test holes.--If exploration along the centerline of the proposed dam shows the presence of permeable materials, consideration should be given to the possible need for foundation drains, relief wells, or both.

Relief wells are usually located at or near the downstream toe of a dam. Foundation drains may be located anywhere between the centerline and the downstream toe, depending on the specific problems and conditions. Either foundation-drainage method, or both, may be necessary to control uplift pressure, to facilitate consolidation, or to prevent piping. In many cases deep foundation drains, consisting of trenches backfilled with properly designed filter materials can be used as an economical alternate for relief wells. This method is suited to many stratified or lenticular materials and to those situations where confined aquifers can be tapped feasibly by excavation.

The design engineer is responsible for determining the kind and location of drainage system to be used. The geologist must recognize the problem, however, and anticipate possible solutions in order to get sufficient information for design.

Exploration must be carried downstream from the centerline to determine the extent and continuity of permeable substrata where foundation drains may be needed. A series of accurately logged borings in the vicinity of the downstream toe, together with centerline information, usually provides enough data for design of the drainage system. Where foundation conditions are highly variable, additional test holes may be needed between the centerline and the downstream toe.

Stream-channel test holes.--If the stream channel contains boulders, roots, debris, and organic matter that cause poor foundation conditions, it may be necessary to remove these materials from beneath the dam as "special stream-channel excavation." Usually, excavation is required from the upstream toe of the dam to a point two-thirds of the distance from the centerline to the downstream toe to prevent leakage through the foundation. Channel investigations provide information on the depth, nature, quantity, and location of the deposits that are to be removed. Sufficient exploration should be made to determine this. If possible, one test hole should be located in the bottom of the channel. Space test holes in stream channels so that the volume of material to be excavated can be estimated closely.

The stream channel may be the best local source of sand or gravel for use in foundation drains, filter blankets, and roadways. The geologist should carefully log and sample these materials, and if they seem to be suitable for these purposes, indicate the need for washing and screening.

Other investigations.--Test holes may be needed at other locations in the general site area. It may be necessary to determine the continuity of materials upstream and downstream throughout the foundation and reservoir area. Information on the depth, nature, quantity, location, and extent of undesirable deposits such as organic soils, very soft silts and clays, and boulders within the foundation area may be needed. Structural features such as faults and contacts may have to be accurately located and their attitude determined through the site area. There may be geologic conditions that require additional subsurface exploration in order to adequately evaluate their effect on the design, construction, and operation of the proposed structure.

Subsurface Exploration. Phase 2: Obtaining Samples

Purpose and Objectives

Some types of samplers used for logging in phase 1 furnish small disturbed samples that are adequate for laboratory testing; others do not. The purpose of phase 2 of the detailed subsurface investigation is to obtain the necessary undisturbed samples and the larger or additional small disturbed samples of unconsolidated materials that are required for soil mechanics testing and analysis.

In phase 1 test holes were bored and logged and various field tests carried out. These data were analyzed and interpreted geologically, and geologic profiles and cross sections were prepared. From a study of these profiles and cross sections and the results of field tests the engineer and the geologist determined what horizons should be sampled and the type, size, and number of samples needed.

The minimum requirements for sampling are outlined by group classification in chapter 5. Sample requirements based on the character of materials and on the tests desired are given in chapter 3. Sampling methods and equipment depend on the character and condition of the material and on the type and size of sample needed (chapter 2).

Holes bored to get undisturbed samples of unconsolidated materials are usually of a larger diameter than those bored for logging. For some situations a different drilling rig from that used in phase 1 must be used or this phase of the investigation must be done by contract, even though SCS-owned equipment was used for logging. The objective is to select locations for these holes so that the required number, size, and type of samples can be obtained with a minimum amount of boring.

Numbering and Locating Sample Holes

Locate sample holes adjacent to the test holes that were bored and logged in phase 1. In this way the depth at which the sample is to be taken can be determined accurately to insure that it represents the selected horizon.

These holes are not logged, and they are given the same Nos. as the logged holes to which they are adjacent. They are not plotted separately

on the plans and profiles, but the symbol for the like-numbered logged holes on the plan is changed from a dot to a circled dot and the sampled segment is delineated on the graphic log.

Investigation of Ground Water

Ground-water conditions may influence the design, construction, and operation of a dam. Where the surface of the underground water (water table) is at or near the ground surface, special design features may be needed to insure stability. In addition special construction procedures may be needed. This condition may eliminate some areas from consideration as a source of borrow material. Where the water table is very low, getting adequate supplies of water to use in construction may be a problem. Artesian water (ground water under enough pressure to rise above the level at which it is reached in a well) may also create special problems.

Impounding water, even temporarily, may modify ground-water conditions. New springs may be created, the flow of springs within the reservoir area may be reversed and they may emerge at a new location, and unsaturated rock or soil materials may become saturated. Other changes in the location and movement of underground water may occur. Frequently, such effects of the structure must be considered before its construction.

Purpose and Objective

The purpose of ground-water studies in dam-site investigations is twofold: (1) To determine present ground-water conditions that may affect the design, construction, and operation of the proposed structure; (2) to determine and evaluate the geologic conditions that may influence the effect of impoundage on ground water.

The objective is to furnish the engineer (1) an analysis of ground-water conditions and (2) an interpretation of the geologic conditions that may influence the effect of impoundage on the location and movement of underground water. This enables him to give due consideration to these problems in planning and in the design and construction of the structure.

Procedure

Examine springs and seeps in the vicinity of the structural site and reservoir area and record their elevation. Where necessary for analysis, prepare a map that shows the location and elevation of springs and seeps. Record any information on source of the water, volume of flow, whether flow is perennial or seasonal, and location of the recharge area. For all test holes that extend below the water table record the elevation of the water table and plot it on the geologic cross sections and profiles. If necessary, prepare a water-table contour map. Record any information on seasonal fluctuation of the water table and note the source of this information. Wait 1 day or longer after drilling to measure the water level in test holes to allow time for stabilization of the water level. Log all artesian aquifers and record any information on the hydrostatic-pressure level and volume of flow. Draw a contour map of the piezometric surface if it is needed.

Locate any permeable materials in the foundation, abutment, and reservoir areas and determine their thickness, elevation, and continuity. Where permeability is a critical factor, obtain values for the coefficient of permeability either by field tests or by laboratory tests on undisturbed samples.

The following field tests are helpful in ground-water investigations.

1. Use of indicators to trace ground-water flow. Water-soluble organic dyes such as sodium fluorescein have been used successfully in many instances.
2. Pressure tests to locate permeable horizons.
3. Pumping-in tests to determine the value of the coefficient of permeability.
4. Use of piezometers.
5. Pumping-out tests.

If local sources of water are adequate for construction purposes but there is some question about the quality of the water, take samples for chemical analysis.

Report of Detailed Geologic Investigation

Narrative Report

In reporting the geologic conditions of a structural site, be as brief and concise as possible but describe all geologic problems thoroughly. Prepare the report in narrative form or use the standard reporting forms, SCS-376A and SCS-376B.

The report must set forth clearly the methods of investigation and the information obtained. Include copies of all field logs in the report.

Prepare a supplement to the report that contains interpretations and conclusions and label it "For In-Service Use Only." This supplement can be prepared on form SCS-376C. Copies of completed plan and profile sheets for geologic investigations must accompany the report supplement.

The following outline can be used in preparing the narrative report.

I. Introduction.
   A. General.
      1. Date of exploration.
      2. Personnel engaged in exploration.
      3. Watershed (name and location).
      4. Site No.
      5. Site group and structure class.
      6. Location.
      7. Equipment used (type, size, makes, models, etc.).
      8. Site data.
         a. Size of drainage area above site (square miles and acres).
         b. Maximum pool depth.

        (1) Sediment pool.
        (2) Flood pool.
        (3) Other pools.
      c. Dam.
        (1) Maximum height.
        (2) Length.
        (3) Location of spillway.
        (4) Volume of fill.
    9. Special methods used.
  B. Surface geology and physiography.
    1. Physiographic area.
    2. Topography.
      a. Steepness of valley slopes.
      b. Width of flood plain.
    3. Geologic formations and surficial deposits.
      a. Names and ages (e.g., Jordan member, Trempealeau formation, Cambrian age; Illinoian till; Recent alluvium).
      b. Description.
      c. Topographic position.
    4. Structure.
      a. Regional and local dip and strike.
      b. Faults, joints, unconformities, etc.
    5. Evidence of landslides, seepage, springs, etc.
    6. Sediment and erosion.
      a. Gross erosion, present and future, by source.
      b. Delivery rates.
      c. Sediment yield.
      d. Storage requirements and distribution.
    7. Downstream-channel stability.
      a. Present channel conditions.
      b. Anticipated effect of the proposed structure.
II. Subsurface geology.
  A. Embankment foundation.
    1. Location and types of test holes and number of samples of each type collected.
    2. Depth, thickness, and description of pervious or low-volume-weight strata. Give detailed data on aquifers or water-bearing zones.
    3. Depth and description of firm foundation materials.
    4. Location, depth, thickness, and description of any questionable materials.
    5. Description of abutment materials, including depth and thickness of pervious layers or aquifers.
    6. Location, attitude, pattern, and other pertinent data on any geologic structural features such as joints, bedding planes, faults, and schistosity.
    7. Location of water table and estimated rate of recharge (high, medium, low).
    8. Permeability of abutments.
  B. Centerline of outlet structure.
    1. Location and type of test holes and number of samples of each type collected.

2. Depth, thickness, and description of pervious or low-volume-weight strata.
3. Depth and description of firm foundation materials.
4. Location, depth, thickness, and description of any questionable materials.
5. Location, attitude, pattern, and other pertinent data on any geologic structural features such as joints, bedding planes, faults, and schistosity.
6. Location of water table and estimated rate of recharge (high, medium, low).

C. Emergency or other open spillway.
   1. Location and types of test holes and number of samples of each type collected.
   2. Location, depth, thickness, and description of materials encountered, including
      a. Hard rock or unconsolidated material to be removed and estimated volume of each.
      b. Material at base of excavation.
      c. Any questionable material.

D. Borrow area(s).
   1. Location of test holes and number and type of samples collected.
   2. Location, depth, thickness, description, and estimated quantities of various types of material.

E. Relief-well and foundation-drain explorations.
   1. Location of test holes and number and type of samples collected.
   2. Description of materials, including location, depth, thickness, and description of pervious strata.

F. Other explorations.
   1. Purpose.
   2. Location of test holes and number and types of samples collected.
   3. Description of materials.

G. Water supply.
   1. Available sources (farm ponds, rivers, wells, municipal, etc.) and quantity.
   2. Quality of available water. If questionable, what samples were taken for analysis.

H. Construction materials (other than earthfill).
   1. Sources of materials for concrete aggregate, riprap, impervious blanket, wells, and drains.
   2. Description, location, and estimated quantities of materials available.

III. Logs.
   Attach completed copies of form SCS-533.

IV. Interpretations and conclusions (for in-Service use).

A. Interpretations.
   1. Interpretations of geologic conditions at the site.
   2. Possible relation of conditions to design, construction, and operation of structure.

B. Conclusions.
   Geologic conditions that require special consideration in design and construction.

C. Attach completed copies of forms SCS-35A, -35B, and -35C.

Report Supplement for In-Service Use Only

Record only basic data and facts in the geologic report. On request, this report is made available for inspection by non-SCS interests. Report separately interpretations, conclusions, and suggestions and label this supplementary report "For in-Service use only" to restrict its use.

From the surface geology and the facts obtained by underground exploration the geologist should interpret geologic conditions at the site and their possible relation to the suitability of the site and to the design, construction, and operation of the proposed structure. Specifically, he should point out any problems likely to result from the geologic conditions, such as foundation weakness, seepage problems, excess ground water during construction, difficulties of excavation, spillway problems, or problems concerning available borrow materials.

The geologist should make recommendations on possible means and methods of overcoming problems that result from the geologic conditions. He should indicate the most efficient use of available materials and of the geologic features of the site. His recommendations might include suggestions to the design engineer on such items as location of the principal spillway, location of the emergency spillway, depth of core trench, and depth of keyways into abutments. He should indicate the need for an impervious blanket, grouting, or other control of excessive water loss. He should point out any special problems that may arise during construction of the dam such as problems of excavation and suitability of the excavated rock for use as riprap, sources of concrete aggregate, and recommendations on sources of water for construction.

Distribution of Geologic Report

Send copies of the geologic report and supplement, including the field logs and completed "Plan and Profiles for Geologic Investigation," to:

1. The EWP Unit geologist for all sites for structures requiring EWP Unit review or approval of the engineering plans.
2. The soil mechanics laboratory to which samples are sent.
3. A copy must accompany the design data, and additional copies are to be distributed as directed by the State Conservationist.

☆ U. S. GOVERNMENT PRINTING OFFICE : 1963 O - 705-782